(12) **EUROPEAN PATENT APPLICATION**

• Chitty, Eymard J.
Trumbull, Connecticut 06611 (US)

(74) Representative: Stagg, Diana Christine
Emhart Patents Department
Emhart International Ltd.
177 Walsall Road
Birmingham B42 1BP (GB)

(54) **Blind rivet system verification system and method**

(57) A blind rivet set verification system for setting a blind rivet assessing the acceptability of the rivet set. The system includes a remote intensified rivet setting tool and computer hardware and software. The tool comprises a displacement transducer that produces a displacement signal and a pressure transducer that produces a pressure signal. The transducers are connected to the computer which receives the distinct signals. These signals are interpreted to plot a displacement-versus pressure waveform and to determine the velocity of the movement of an air piston that responds to the rivet set by hydraulic pressure. Using the combined date of the velocity waveform and the displacement-versus pressure waveform, the breakload is identified and compared against predetermined ideal data to assess the acceptability of the set. The displacement reading at break is corrected for jaw slippage and offset of the air piston.

Fig-1
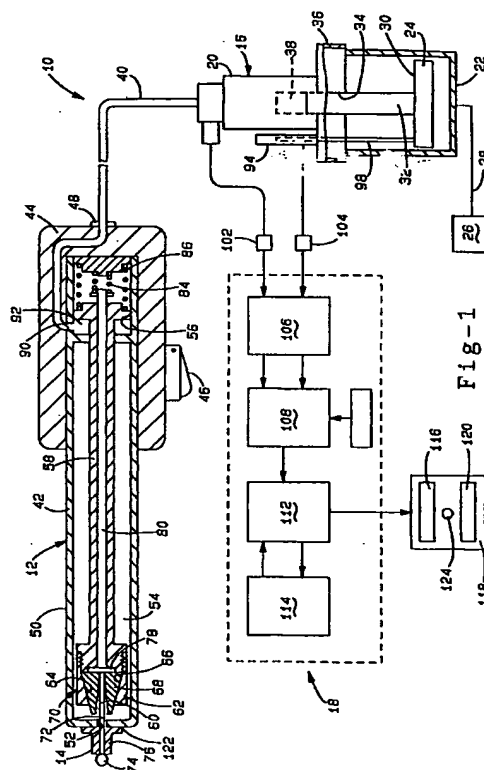
Description

This invention relates to the setting of blind rivets. More particularly, this invention relates to a blind rivet setting system in which a blind rivet is first set and then the correctness of the set of the rivet is verified.

Rivets are widely used to firmly fasten together two or more components of little susceptibility to loosening and thus to produce a tight joint at a low cost.

The setting of the common rivet is accomplished when one end of the rivet is mechanically deformed to create a second head. The blind rivet is a special class of rivet that can be set without the need for mechanical deformation by a separate tool to create the second head. Special blind rivet setting tools are used for setting these types of rivets. Examples of setting tools are disclosed in U.S. Patent No. 3,713,321, U.S. Patent No. 3,828,603 and U.S. Patent No. 4,263,801. These tools provide various approaches to setting rivets including setting by hydraulic and pneumatic power. A relatively sophisticated version of a blind rivet setting tool is disclosed in U.S. Patent No. 4,744,238. This setting tool includes a rivet feed mechanism, a rivet magazine and sequencing controls providing cycle-through operation that utilises pneumatic logic control. A self-diagnosing blind rivet tool is disclosed in U.S. Patent No. 4,754,643. This patent is directed to an automated and semi-automated rivet installation system that has the ability to diagnose selected tool conditions and to convey information on the conditions to the operator. Monitored conditions include the rivet placement within the tool, mechanism positions, and air pressure conditions.

One common shortcoming of prior art apparatus for the installation of blind rivets is the inability of the operator to gauge the correctness of the rivet set which cannot be readily determined by observation or touch. This is because the second head is created on the far side (or the blind side) of the elements being riveted. In response to this need, it has been suggested that an electroacoustic transducer be used to convert the mechanical braking of the mandrel at the conclusion of the setting process to an electric signal for determination of the correctness of the set. It has been further suggested that a strain gauge be employed to sense the setting force of the rivet. These methods, however, provide the operator with limited set condition information. Consequently, the set condition of the rivet is assessible only in a marginal way.

Accordingly, there is still a need for a system by which a blind rivet may be first set and then the correctness of the set fully and reliable verified.

It is an object of the present invention to overcome the disadvantages associated with known blind rivet setting tools by providing an improved rivet setting and correctness verification system.

It is a further object of the present invention to provide a system which measures the pressure of hydraulic fluid acting on a rivet mandrel required to set a rivet.

Yet a further object of the present invention is to provide such a system which measures the displacement of a fluid-moving piston through a rivet setting cycle.

Still another object of the present invention is to provide such a system in which the pressure measurement and displacement are assimilated to produce a pressure-versus-displacement waveform.

A further object of the present invention is to provide a set verification system according to the present invention in which a velocity waveform is calculated based upon mandrel displacement over time.

Yet still a further object of the present invention is to obtain several rivet standards by examining the various peaks and valleys present in the pressure-versus-displacement waveform and the velocity waveform and comparing these standards against predetermined ideal values to assess the set.

The present invention provides a system for setting a blind rivet and evaluating the acceptability of the set, said rivet being of the type having a frangible tubular body and an elongated mandrel that includes an enlarged head and a stem extending rearwardly of the head and through said frangible tubular body, characterised in that said system comprises:

a hydraulically-operated blind rivet setting tool, said tool including a rivet pulling head for gripping and pulling said stem of said mandrel, said tool further including a hydraulic intensifier and a hydraulic line fluidly connecting said hydraulic intensifier with said pulling head, said hydraulic intensifier including a hydraulic fluid part and an air piston part, said hydraulic fluid part including a hydraulic fluid cavity and said air piston part including an air cylinder, said intensifier further including a piston assembly, said piston assembly including an air piston axially movable within said air cylinder and a shaft extending therefrom and operably movable within said hydraulic fluid cavity of said hydraulic fluid part;

a first transducer for measuring the hydraulic pressure of said setting tool applied to pull said rivet during a rivet set, said transducer being provided in operative association with said tool and adapted to produce a pressure output signal related to said pressure applied to pull said rivet during a rivet set;

a second transducer for measuring the axial displacement of said piston assembly, said second transducer being provided in operative association with said tool and adapted to produce a displacement output signal related to the displacement of said piston assembly; and

a control circuit, said control circuit having circuitry to:

(a) receive said pressure output signal and said displacement output signal sequentially;

(b) produce from said pressure output signal and said displacement output signal a pressure-versus-displacement waveform and a velocity waveform;

(c) scan said velocity waveform to determine the highest value of velocity;

(d) use the determined highest value of velocity as the starting point for scanning said pressure-versus-displacement waveform to identify the mandrel breakpoint;

(e) compare the actual value of the breakpoint with a predetermined desired value.

The invention will now be described in more detail with reference to the accompanying drawings, in which:

Figure 1 is a combined pictorial and block diagram of the blind rivet setting apparatus according to the present invention showing the setting tool and intensifier components in partial cross-section;

Figure 2 shows a co-ordinate graph illustrating a pressure-versus-displacement waveform for a blind rivet being set with displacement measured along the X-axis and pressure measured along the Y-axis;

Figure 3 shows a co-ordinate graph similar to that shown in Figure 2 but having an additional velocity waveform superimposed on the pressure-versus-displacement waveform;

Figure 4 is a control flowchart of illustrative breakload analysis steps in accordance with this invention;

Figure 5 shows the co-ordinate graph of Figure 3 but illustrating specific points identified in making a breakload analysis;

Figure 5a is an enlarged region of Figure 5 illustrating the breakload peak;

Figure 6a is a sectional view of a workpiece comprising two plates held together by a rivet set at a correct grip;

Figure 6b is a sectional view of a workpiece comprising a single plate with a rivet set at an incorrect undergrip;

Figure 6c is a sectional view of a workpiece comprising three plates held together by a rivet set at an incorrect overgrip;

Figure 7 shows a co-ordinate graph illustrating a pressure-versus-displacement waveform for a blind rivet being set by a tool experiencing jaw slippage with displacement being measured along the X-axis and pressure measured along the Y-axis;

Figure 7a is an enlarged region of Figure 7 graphically illustrating jaw slippage;

Figure 8 shows a co-ordinate graph illustrating a pressure-versus-displacement waveform for a blind rivet being set by a tool experiencing air piston offset with displacement being measured along the X-axis and pressure measured along the Y-axis;

Figure 9a shows an elevated sectional view of the intensifier of the present invention with no loss of oil;

Figure 9b is similar to the view of Figure 9a but illustrating the intensifier as having lost some oil;

Figure 10a shows a bell curve produced from an intensifier experiencing no air piston offset;

Figure 10b shows a bell curve produced from an intensifier experiencing air piston offset;

Figure 11 is a control flowchart of illustrative undergrip-overgrip analysis steps in accordance with this invention;

Figure 12 is a control flowchart of illustrative clamp analysis steps in accordance with this invention;

Figure 13 shows a co-ordinate graph illustrating both a pressure-versus-displacement waveform and a velocity waveform for a rivet demonstrating a good clamp with displacement being measured along the X-axis and pressure measured along the Y-axis;

Figure 13a is a sectional view of a workpiece comprising two plates held together by a rivet demonstrating good clamp characteristics;

Figure 14 is a graph similar to that of Figure 13 but showing waveforms for a rivet demonstrating a bad clamp;

Figure 14a is a sectional view of a workpiece similar to that of Figure 13a but demonstrating bad clamp characteristics; and

Figure 15 is a control flowchart of illustrative entry load analysis steps in accordance with this invention.

Reference is first made to Figure 1 wherein the system for setting blind rivets and for verifying the acceptability of their set according to the present invention is generally illustrated as 10. The system 10 includes a rivet mandrel pulling tool 12 for setting a blind rivet 14, a remote intensifier 16, and a system control circuit 18.

The intensifier 16 includes an oil cylinder 20 and an air cylinder 22. The air cylinder 22 includes a piston 24 that reciprocates within the cylinder 22 in response to pressure created by a pressure source 26. The pressure source 26 is fluidly connected to the cylinder 22 by a fluid line 28. Pressure is conventionally provided to the air cylinder 22 between 80-85 p.s.i. While it is possible to integrate the intensifier 16 with the tool 12 itself, this is not a desirable approach in that electrical wiring connecting the tool 12 and the intensifier 16 would be required and thus susceptible to failure. In addition, the remoteness of the intensifier virtually eliminates tool access problems. It is accordingly pre-

ferred that the intensifier 16 be remotely situated from the tool 12 as illustrated.

The piston 24 includes a substantially planar top side 30 to which is connected a reciprocating shaft 32. The shaft 32 is positioned through an arm passing aperture 34 defined in a cylinder end cap 36. The free end of the shaft 32 terminates in an oil cavity 38 defined in the oil cylinder 20. Pneumatic oil is provided within the cavity 38.

5   The fluid of the oil cavity 38 is continuous with the rivet mandrel pulling tool 12 through a flexible hydraulic hose 40. The tool 12 comprises an elongated body generally illustrated as 42. While the body 42 may be of any of several constructions, it is preferably provided with a handle 44 as shown. A trigger 46 which actuates the tool 12 is fitted in the handle 44 in a conventional manner and is operatively associated with a valve 48.

The elongated body 42 includes an elongated housing 50. The housing 50 includes a mandrel-passing aperture

10   52 defined in its fore end. While not limited to this construction, the housing 50, as illustrated, is subdivided internally into a fore chamber 54 and a hydraulic cylinder chamber 56. The elongated body 42 includes an axially movable pulling shaft 58 provided along its long axis. It must be understood that the construction of the housing 50 may be varied in many ways, with its only essential feature being that it provide support for the pulling shaft 58 and for a means of axially moving the shaft.

15   A jaw assembly 60 is operatively associated with the fore end of the pulling shaft 58. The jaw assembly 60 includes a jaw cage 62 having an internal bevelled wedging surface 64 that defines an internal bore 66. An array of split jaws 68 are movably provided within the cage 62. When the outer surfaces of the split jaws 68 act against the bevelled surface 64, the jaws 68 engage and grip an elongated stem 70 of a mandrel 72 of the blind rivet 14. The mandrel 72 also includes a rivet head 74. The mandrel 72 comprises the head deforming component of the rivet 14 as is known

20   in the art. The rivet 14 includes a tubular deformable sleeve 76. A variety of methods may be employed to manipulate the jaw assembly 60 to grasp and hold the stem 70 of the mandrel 72. While one such method is discussed hereafter, the various methods of construction of rivet setting tools are well known to those skilled in the art, and it is accordingly to be understood that the following construction is only illustrative and is not intended to be limiting.

According to the illustrated construction of the present invention, a pusher 78 is fixed to the forward end of a pusher

25   rod 80. The pusher rod 80 is provided within a central throughbore defined in the pulling shaft 82. The pusher rod 80 is axially movable within this throughbore and is biased at its aft end against the back wall of the hydraulic cylinder chamber 56 by a spring 84. A weaker spring 86 acts between the same wall and the aft end of the pulling shaft 58.

A piston 88 is fixed to the pulling shaft 58 and is capable of axial motion in both fore and aft directions within the hydraulic cylinder chamber 56. The pressure source 26 forces a pressurised fluid (not shown) through the fluid line 28

30   into the cylinder chamber 56 on the forward side of the piston 88 through a pressurised fluid port 90 into a pressurisable side 92 of the hydraulic cylinder chamber 56. By introducing a pressurised fluid into the fluid-tight chamber defined within the pressurisable side 92, the piston 88 is forced to move aftward causing the stem 70 to break from the head 74 as described below.

The tool 12 is fluidly connected with the remote intensifier 16 through the flexible hose 40. Provided in operative

35   association with the intensifier 16 are transducers to measure hydraulic fluid pressure and axial displacement of the movable components of the cylinders 20 and 22. These transducers include a linear encoder 94 and a pressure transducer 96.

The linear encoder 94 (an analog voltage-output displacement transducer or other suitable displacement measuring device such as a linear differential transformer) is provided in operative association with the air piston 24 through

40   a movable rod 98 fixed to the side 30 of the piston 24. The rod 98 moves axially with the piston 24. The encoder 94 produces an output signal (S) related to the linear displacement of the piston 24. Specific placement of the transducer 94 as shown in Figure 1 is only illustrative, and this component may be placed elsewhere on the cylinders 20 and 22, provided that it is in operative association with either the piston 24 or the shaft 32.

The pressure transducer 96 is in fluid communication with the hydraulic oil and hence is provided between the oil

45   cavity 38 and the tool 12. The transducer 96 may be selected from a variety of types and is adapted to sense the amount of hydraulic pressure applied to the pulling head 12 during the rivet setting process and produce an output signal (P) related to this pressure.

The system control circuit 18 includes signal conditioning circuits 102 and 104 which receive outputs transmitted from the pressure transducer 96 and the linear encoder 94 respectively. The pressure (P) and displacement (S) signals,

50   converted from their analog form to a digital form in the signal conditioning circuit 102 and 104, are supplied through an amplifier 106 to an integrator circuit 108 which monitors the sensed signals throughout the riveting cycle. The integrator circuit 108 reads the pressure (P) and displacement (S) signals sequentially during the setting cycle, sampling each transducer circuit in 1 millisecond increments over a total time of one second.

The integrator circuit 108 uses this data to develop selected waveforms. One of these waveforms, shown graph-

55   ically in Figure 2, is a pressure-versus-displacement waveform with displacement (measured in inches) measured along the X-axis and pressure (measured in pounds per square inches) and load (measured in pounds) measured along the Y-axis. The integrator 108 also reads displacement signals over increments of time to develop a velocity waveform. A timer 110 is integrated with the circuit 108. The velocity waveform is shown in Figure 3 superimposed on

a pressure-versus-displacement waveform. Because both displacement and time are known, velocity can be calculated as follows:

$$v1 = \frac{d2 - d1}{t2 - t1} \quad \text{and} \quad v2 = \frac{d3 - d2}{t3 - t2} \quad \text{and} \quad vx = \frac{d(x+1) - d(x)}{t(x+1) - t(x)}$$

where v = velocity, d = displacement, t = time, x = memory location
(note: t(x+1)-t(x) always equals 2mS, 1mS sampling rate per transducer)

As one would expect, and as illustrated in Figure 3, the velocity of the air piston rises as the pressure falls. The reverse is also true, and, again, this may be understood by reference to Figure 3.

The integrator circuit 108 analyses each waveform and produces output signals representative of predetermined characteristics of the observed waveforms (including, for example, particular peaks and valleys). These output signals are supplied to a comparator circuit 112 which compares the observed waveform characteristics with the corresponding characteristics of an experimentally-derived waveform stored in a programmed reference 114 for the setting of the particular rivet involved. If the actual observed characteristics of the set are within predefined acceptable set ranges of the prestored values, a green light 116 on a visual display 118 is illuminated. If on the other hand the actual observed characteristics of the set are outside the prescribed set value ranges, a red light 120 is illuminated. A graph, such as a correct-versus-incorrect set graph, may be produced in lieu of the single green light-red light combination. The form of the output would depend on the needs of the particular application. (As an alternative to the described construction, the circuit 112 may comprise software to control the functioning of the hardware and to direct its operation.)

A variety of analyses can be performed using the present invention to determine the correctness of the set, with the more significant ones set forth below. While the set verification operations that follow are discussed individually on an analysis-by-analysis basis, this is done for the sake of clarity, and it is preferred that all of them be made for each rivet set using the same set of collected pressure and displacement data.

The name "blind rivet" is derived from the fact that such rivets are installed from only one side on an application, the primary side. The blind rivet 14 includes the tubular rivet sleeve 76 having a flange 122 at the aft end of the sleeve 76. In the illustrated initial cycle position, the head 74 remains adjacent the forward end of the sleeve 76.

When a rivet is set in the workpiece (not shown), the mandrel 72 is held between the split jaws 150 and is pulled by the setting tool. As the pulling shaft 58 is forced aftward by fluid pressure against the resistance of the weaker spring 86, the pusher rod 80, biased against the stronger spring 84, resists aftward movement, causing the pusher 78 to act against the aft sides of the split jaws 68. The outer surfaces of the split jaws 68 act against the internal bevelled wedging surface 64 to grip the stem 70. Once the stem 70 is gripped and the split jaws 68 are fully lodged between the surface 64 and the stem 70, the pusher rod 80 moves aftward with the pulling shaft 58, the biasing force of the stronger spring 84 now overcome.

As the jaw assembly 60 is carried aftward by movement of the pulling shaft 58, the head 74 of the rivet 14 enters the sleeve 76. This is denoted the "entry point", and is the point at which the sleeve 76 begins to deform. As the mandrel 72 continues to be pulled, the rivet sleeve 76 is deformed up to the secondary side of the workpiece. The deformed part of the sleeve 76 acts as the secondary clamp element, whereas the flange 122 becomes the primary clamp element. It is the combination of the secondary and primary clamp elements that holds two or more parts of an application together.

Continued aftward movement of the jaw assembly 60 by movement of the pulling shaft 58 pulls the head 74 into the sleeve 76 causing its maximum deformation. Once the head 74 reaches the secondary side, the mandrel 72 breaks off from the head 74 at its crimp, this representing the breakload, and the secondary clamp element is created by the combination of the now-unattached head 74 and the sleeve 76.

When fluid pressure within the side 92 is released, both the pulling shaft 58 and the pusher rod 80 are restored to their preengaged positions by the biasing forces of the springs 84 and 86. With the force on the jaws 68 removed, the jaws 68 are relaxed to their preengaged positions and the stem 70 is released and discarded. The tool 12 is then ready to repeat its cycle.

Breakload relates to the breaking of the stem from the head of the rivet. If the breakload is either too great or too small, according to upper and lower predetermined desired specifications for the particular rivet and stored in the programmable reference, the set is rejected.

The system control circuit 18 includes a programmed control algorithm to analyse the breakload. The control algorithm used to analyse breakload is described by reference to a breakload analysis flow chart shown in Figure 4 in which an exemplary operation flow of the analysis is set forth.

Operation of the tool 12 is initiated via actuation of the trigger 46. The control algorithm makes an initial query at Step 200 as to whether or not the tool has, in fact, been operated. When it is found that the tool has not been operated, the cycle is reset to the initial query until there is verification that the tool has been operated.

Once operation of the tool 12 is verified, the algorithm collects the pressure (P) and displacement (S) data at Step 202 and produces a pressure-versus-displacement waveform (PVD) at Step 204 and, by timing displacement, produces a velocity waveform (V) at Step 206.

As is known and as is demonstrated in Figure 5 which shows the co-ordinate graph of Figure 3 but which illustrates particular points identified in making a breakload analysis, the highest point on the pressure-versus-displacement waveform occurs immediately after the break of the mandrel stem from the head, this point usually occurring at a mandrel velocity greater than 10 inches per second. Just to the right of this point the air piston 24 reaches the end of its stroke thus causing the velocity to fall to a minimum, as illustrated in Figure 5. The algorithm then moves to Step 208 where the integrator circuit 108 searches for a point on the velocity waveform having a quickly moving displacement, such as greater than 5 inches per second. This point is identified as Point A on the graph of Figure 5. With Point A established, the algorithm proceeds to Step 210 where the integrator circuit 108 refers a certain number of memory locations back along the velocity waveform to establish a second point, Point B. In this example, Point B is approximately 50 memory locations preceding Point A. The reason for referring back a certain number of memory locations is to ensure the establishment of Point B at a point on the graph prior to the setting of the rivet.

With Points A and B established, the algorithm then moves to Step 212 in which the integrator circuit 108 searches every location between Point B on the left and Point A on the right for the greatest velocity value. Once this location is identified, the algorithm proceeds to Step 214, and the point identified as the greatest velocity value becomes the reference to begin looking for the breakpoint on the pressure-versus-displacement waveform. The breakpoint is identified by looking for a sudden drop in the pressure value. This is accomplished by comparing each point on the pressure-versus-displacement waveform to the next pressure sample and determining the total difference between the two values. When a drop in pressure greater than a predetermined amount is identified, this location is the breakpoint. Thereafter, the pressure at the breakpoint is converted to a breakload value (in pounds or grams) by multiplying the pressure (in pounds per square inch or grams per square centimetre) by the area of the piston (in square inches or in square centimetres).

The algorithm then moves to Step 216 to compare the breakload value with upper and lower specifications of the rivet. If at Step 216 it is determined that the breakload value is not within the predetermined range, the set is rejected and the red light 120 is illuminated indicating to the operator that the set is unacceptable. Conversely, if the breakload valve is within the predetermined range, the set is accepted and the green light 116 is illuminated and the algorithm returns to start to await the next cycle.

Because the pressure transducer 96 and the displacement transducer 94 are monitored by the integrator circuit 108 sequentially, the location in the memory of the circuit 108 adjacent to the pressure peak at the breakpoint established in the breakload analysis will be the total displacement of the piston 24 at the breakpoint. This is illustrated in the following memory map:

loc x	Pressure	Samples taken at 1mS intervals
loc x+1	Displacement	
loc x+2	Pressure	
loc x+3	Displacement	
loc x+4	Pressure	
loc x+5	Displacement	
loc x+6	Pressure	

The value of total piston displacement at breakpoint can be compared by the comparator circuit 112 to known upper and lower values stored in the programmable reference 114. If the axial movement of the air piston 24 is within an acceptable range, the operator is so notified by correct signal shown as the illumination of the green light 116 provided on the display 118. A rivet set having a correct grip is demonstrated in Figure 6a which shows a sectional view of a workpiece comprising two plates A and B held together by a rivet R. If the axial movement of the air piston 24 is, in fact, too large, an undergrip situation results, because the air piston 24 moved too far at rivet set. The resulting set is graphically illustrated in Figure 6b which is a sectional view of a workpiece comprising (for illustrative purposes) a single plate C and a rivet R' with the rivet set at an incorrect undergrip. As illustrated, the secondary head is formed with an excessive amount of deformed tubular material.

If the value of the displacement at the breakpoint is, in fact, too small, then an overgrip situation is indicated resulting

from the fact that the air piston 24 did not move far enough at rivet set. The result of the overgrip situation is graphically illustrated in Figure 6c which shows a sectional view of a workpiece comprising three plates D, E and F held together by a rivet R".

Determining the correctness of the grip so as to distinguish between a correct set, an undergrip situation and an overgrip situation, it is necessary to have an accurate displacement reading at breakpoint. However, the accuracy of the value assigned to piston displacement is dependent on two factors that have to be considered: Slippage of the mandrel-holding jaw and offset of the air piston.

With respect to jaw slippage, this phenomenon occurs generally when the jaws in the pulling head of the tool 12 become dirty or worn, or if the mandrel material is too hard, thus causing the jaws to lose their grip on the mandrel as they are pulled back to set the rivet. When jaw slippage occurs, the hydraulic pressure drops slightly until the jaws regrip the mandrel. Figure 7 illustrates a pressure-versus-displacement waveform for a blind rivet being set by a tool experiencing jaw slippage. The jagged appearance of the waveform, as seen more clearly in Figure 7a which is an enlarged region of Figure 7, graphically demonstrates how the tool experiences slippage and then repeatedly attempts to regrip the mandrel. Of course, as may be understood by reference to the graph, jaw slippage will affect overall displacement at the breakpoint.

The present invention provides a method by which accurate displacement values are determined in spite of the phenomenon of jaw slippage. Specifically, because jaw slippage affects the total displacement of the air piston at the breakpoint, the pressure-versus-displacement waveform is monitored and displacement that occurs below 300 pounds per square inch is ignored. This allows time for the jaws to position and grip themselves onto the mandrel body. Each time the jaws experience slippage, the pressure drops, and the displacement is noted. When the jaws regrip the mandrel and the pressure again begins to rise, the displacement reading is again noted. The difference between the two readings is calculated and subtracted from the overall displacement at break, thereby compensating for slippage. The entire pressure-versus-displacement waveform is searched by the integrator 108 for jaw slippage and each time any slippage is found the compensating procedure is repeated. (It is likely that once the jaws slip a first time there will be evidence of additional slippage throughout the waveform.)

In addition to compensating for the slippage to produce accurate displacement values, the operator can also be notified by the circuit 18 that, in fact, slippage has occurred through a slippage warning light 124 on the display 118. Illumination of the light 124 will alert the operator that tool maintenance is required. This can prove a useful preventive maintenance procedure in that as early stages of jaw slippage do not substantially affect tool efficiency, more severe slippage requires multiple tool cycles to set each rivet, thus wasting both time and energy.

Another factor that must be considered to achieve a correct displacement reading at breakpoint is the effect of offset of the air piston 24 on the pressure-versus-displacement waveform. Figure 8 illustrates the effect of offset due to a lowering of hydraulic pressure on the pressure-versus-displacement waveform.

In use, an operator may set up to 30 rivets per minute. Because of the relatively high frequency of rivet sets, it is known that the air piston 24 may not fully return to the home position before the next cycle begins. This offset of the air piston 24 has to be considered when determining the total displacement of the air piston 24 at the breakpoint. To determine and therefore compensate for this offset, the amount of piston displacement at the start of the rivet setting process (relative to a predetermined starting position) is noted by the integrator circuit 108 based on signals generated by the displacement transducer 94. This value is then subtracted from the total displacement observed at the breakpoint to achieve the true displacement during the rivet setting process, thus compensating for offset.

Another factor that will affect the true displacement of the air piston at the breakpoint is loss of hydraulic oil. If the tool loses oil, the air piston 24 will not return fully to its home position. Figure 9a shows an elevated sectional view of the intensifier 18 of the present invention showing no loss of oil from the cavity 38. As may be seen, the air piston 24 is situated in its home position close to the base of the cylinder 22. Conversely, Figure 9b, while similar to that of Figure 9a, illustrates an intensifier 16 that has experienced a loss of some oil from the cavity 38. The loss of this oil results in the offsetting of the air piston 24 from its normal home position shown in Figure 9a to a displaced position slightly further away from the end wall of the cylinder 22 shown in Figure 9b.

When the tool looses enough oil, the stroke of the tool 12 is accordingly reduced, and the tool becomes inefficient by requiring more than one pull to set a rivet. Although the tool has a certain amount of oil reserve before the stroke is affected, the oil loss may be monitored by checking the displacement of the air piston 24, thus having the ability to predict failure before it occurs. Bell curves demonstrate differences in operation caused by loss of oil. Figure 10a shows a bell curve produced from an intensifier experiencing no air piston offset. This is a correct and desirable bell curve. Conversely, Figure 10b shows graphically a bell curve produced from an intensifier experiencing air piston offset thus resulting in an undesirable curve and, more importantly, an offset air piston 24.

The operations in the undergrip-overgrip analysis set forth above are managed by a programmed control algorithm included in the system control circuit 18. The undergrip-overgrip control algorithm used will now be described by reference to a flow chart shown in Figure 11 in which an exemplary overall undergrip-overgrip operation flow of the present invention is set forth.

As with the breakload analysis set forth above, operation of the tool 12 is initiated via actuation of the trigger 46. After making an affirmative determination at the initial query at Step 200 as to whether or not the tool has been operated, the algorithm collects the pressure (P) and displacement (S) data at Step 202 and, at Step 204, produces a pressure-versus-displacement waveform (PVD), all as set forth above with respect to breakload analysis. Also as with breakload analysis, a velocity waveform (V) is produced at Step 206, after which the algorithm moves forward to Step 208 to search for Point A and then to Step 210 to establish Point B. Once Points A and B are established, the algorithm moves to Step 212 to identify the location between Points A and B representing the greatest velocity value. At Step 214, the breakpoint is identified, again according to the previously discussed breakload analysis.

As noted above, because the pressure and displacement transducers are monitored sequentially, the location in the computer memory adjacent to the pressure peak breakpoint is identified as the total displacement of the piston 24 at breakpoint, and the algorithm moves to Step 218 to make this identification. Once breakpoint displacement of the piston 24 is established, the algorithm moves forward to Step 220 at which point compensation is made for jaw slippage by identifying periods of displacement when observed pressure values are below 300 pounds per square inch, and subtracting these displacement amounts from the overall displacement at break as set forth above. This step is repeated for each instance of jaw slippage. Compensation for jaw slippage completed, the algorithm moves forward to Step 222 at which point compensation for offset is made by determining the value of offset displacement and subtracting this value from the displacement at break, also as set forth above.

Compensation for slippage and offset completed, the algorithm moves forward to Step 224 to compare the value representing actual compensated displacement at break against a value representing ideal displacement at break. If at Step 224 it is determined that the value representing actual compensated displacement at break is not within a predetermined range of values of the ideal break, the set is rejected and the red light 120 is illuminated indicating to the operator that the set is unacceptable. On the other hand, if at Step 224 it is determined that the value of actual compensated displacement at break is acceptable, then the green "correct" light 116 is illuminated.

If the rivet sleeve 76 is composed of a material that is too hard, or if the material of the mandrel 72 is composed of a material that is too soft, or if the crimp on the mandrel is not to specifications, the secondary clamp element may not pull all the way to the secondary side of the workpieces prior to breakage. There is also the possibility that the mandrel head may not even enter the rivet body. In either event, the result is a loose and undesirable set. The rivet set verification system of the present invention is adapted to monitor this condition by way of a programmed control algorithm to analyse the clamp condition. The control algorithm used to analyse the clamp is included in the control circuit 18 and is described by reference to a clamp analysis flow chart shown in Figure 12 in which an exemplary operation flow of the clamp analysis is set forth.

Once operation of the tool 12 is confirmed at Step 200 and pressure (P) and displacement (S) data are collected at Step 202 as set forth above with respect to breakload analysis, the algorithm moves to Step 206 to produce a velocity waveform.

The waveform produced at Step 226 graphically represents the analysis of the clamp. When the mandrel head enters the rivet body the velocity of the air piston 24 rises due to a drop in hydraulic pressure as the rivet body collapses. The algorithm moves forward to Step 226 to monitor this rise, which is graphically demonstrated in Figure 13 as Point C. Figure 13 shows a co-ordinate graph illustrating both a pressure-versus-displacement waveform (for comparison) and a velocity waveform for a rivet set. With the algorithm proceeding next to Step 228, the velocity waveform is monitored until Point D is found. Point D is the point where the mandrel head has reached the secondary side of the application. The difference between Point C and Point D determines whether secondary head formation or clamp is correct. The correctness of this difference is determined by using the comparator circuit which compares the value derived from the set with the predetermined desired value stored in the programmable reference 114. At Step 230, the difference between Points C and D (measured along the Y-axis) is determined, and this difference is compared against a predetermined range for an ideal difference. A correct set is illustrated in Figure 13a which is a sectional view of a workpiece comprising two plates, labelled C and D, held together by a rivet R. With this correct set being identified at Step 232, the green light 116 is illuminated.

Figure 14 is a graph similar to that of Figure 13 but illustrating a waveform in which the difference between Points C and D is considerably less than that between Points C and D of Figure 13. This small difference is not enough to constitute a good clamp situation. The resulting bad clamp is demonstrated in a sectional view in Figure 14a, illustrating a rivet R' fastening together two plates, C and D. This type of bad clamp typically indicates an overgrip situation, as the air piston 24 did not move the specified distance at the breakpoint. The operator is apprised of the incorrect set by illumination of the red light 120.

If a rivet has a known specified entry load, the desirability of the load produced at the actual set can be compared against predetermined desirable values to determine the correctness of the set. The system control circuit 18 includes a programmed entry load analysis algorithm that is set forth in a flow chart shown in Figure 15. As with the other analyses set forth above, Step 200 confirms that the tool 12 has, in fact, been operated, and once so confirmed, pressure (P) and displacement (S) data are collected at Step 202. As with the above-described breakload analysis,

the algorithm proceeds forward to Step 204 to produce a pressure-versus-displacement waveform (PVD) and then next proceeds to Step 206 to produce a velocity waveform (V). Thereafter the algorithm proceeds to Step 226 to scan the velocity waveform to find Point C in Figure 13. Once point C is identified, the algorithm moves onto Step 232 which cross-references the location of Point C to identify a Point E on the pressure-versus-displacement waveform that is equidistant from the Y-axis, or the load-pressure axis. The cross-referenced value at Point E is then converted to a load in pounds. The algorithm next moves to Step 234 to compare the converted value against the predetermined preferred entry load value. As with the previously discussed analyses, if the actual entry load is not within the predetermined preferred entry load range, the set is rejected and the red light 120 is illuminated indicating to the operator that the set is unacceptable. Conversely, if the set is within the acceptable range, the green "correct" light 116 is illuminated.

Instead of clamping the pieces together, occasionally the secondary rivet head is formed but does not hold the pieces together but is rather simply pulled through the aperture within which the tubular body is provided for clamping. A pull-through situation occurs typically because either the hole size is too large, the rivet body material is too soft, the mandrel crimp is not in the correct location, the grip is out of the acceptable range as known, or the mandrel crimp breakload is too high. (The latter situation arises where the mandrel material is too hard or is incorrectly heat treated, or if the tubular body is too shallow to crimp.) A visual indication of a pull-through situation would reveal part of the mandrel protruding from the rivet body after the rivet is set. If any of these conditions arise, the entry load will probably be too low and an undergrip situation will occur. The operator is so notified after entry load and undergrip-overgrip analyses are made as set forth above.

Claims

1. A system for setting a blind rivet and evaluating the acceptability of the set, said rivet being of the type having a frangible tubular body and an elongated mandrel that includes an enlarged head and a stem extending rearwardly of the head and through said frangible tubular body, characterised in that said system comprises:

   a hydraulically-operated blind rivet setting tool, said tool including a rivet pulling head for gripping and pulling said stem of said mandrel, said tool further including a hydraulic intensifier and a hydraulic line fluidly connecting said hydraulic intensifier with said pulling head, said hydraulic intensifier including a hydraulic fluid part and an air piston part, said hydraulic fluid part including a hydraulic fluid cavity and said air piston part including an air cylinder, said intensifier further including a piston assembly, said piston assembly including an air piston axially movable within said air cylinder and a shaft extending therefrom and operably movable within said hydraulic fluid cavity of said hydraulic fluid part;
   a first transducer for measuring the hydraulic pressure of said setting tool applied to pull said rivet during a rivet set, said transducer being provided in operative association with said tool and adapted to produce a pressure output signal related to said pressure applied to pull said rivet during a rivet set;
   a second transducer for measuring the axial displacement of said piston assembly, said second transducer being provided in operative association with said tool and adapted to produce a displacement output signal related to the displacement of said piston assembly; and
   a control circuit, said control circuit having circuitry to:

      (a) receive said pressure output signal and said displacement output signal sequentially;
      (b) produce from said pressure output signal and said displacement output signal a pressure-versus-displacement waveform and a velocity waveform;
      (c) scan said velocity waveform to determine the highest value of velocity;
      (d) use the determined highest value of velocity as the starting point for scanning said pressure-versus-displacement waveform to identify the mandrel breakpoint;
      (e) compare the actual value of the breakpoint with a predetermined desired value.

2. The system for setting a blind rivet of claim 1 wherein said hydraulically-operated blind rivet setting tool further includes a compressor unit for operating said air piston, said tool further including a fluid line for fluidly connecting said compressor unit with said air cylinder.

3. The system for setting a blind rivet of claim 1 further including a pressure signal conditioning circuit provided between said first transducer and said control circuit and a displacement signal conditioning circuit provided between said second transducer and said control circuit.

4. The system for setting a blind rivet of claim 1 further including an indicator operatively attached to said control circuit for signalling to an operator the correctness of the set based on said comparison of said actual breakpoint against said predetermined desired value.

5. The system of claim 1 wherein said first transducer for measuring hydraulic pressure is an electrical pressure transducer and wherein said second transducer for measuring axial displacement of said piston assembly is a linear variable differential transformer.

6. The system of claim 1 wherein said control circuit includes an integrator, a comparator connected with said integrator, and a programmable memory connected with said comparator.

7. A method for setting a blind rivet having a mandrel and for evaluating the acceptability of the set, said method including the steps of:

setting a blind rivet in a desired position with a hydraulically-operated blind rivet setting tool having a hydraulic pressure intensifier, said intensifier including an axially movable piston assembly, said tool further including a mandrel gripping jaw assembly for gripping and pulling said mandrel;
monitoring the hydraulic pressure required to set said blind rivet during the rivet setting process with a first transducer to produce pressure signals;
monitoring the axial displacement of said piston assembly during said rivet setting process with a second transducer to produce displacement signals, said monitoring of said pressure signals and said displacement signals being done sequentially;
producing a pressure-versus-displacement waveform based on said pressure signal and said displacement signal;
producing a velocity waveform based on said displacement signals over time;
scanning said velocity waveform to determine the highest value of velocity;
using the determined highest value of velocity as a starting point for scanning said pressure-versus-displacement waveform to identify the mandrel breakpoint; and
comparing the actual value of the breakpoint with a predetermined desired value.

8. A system for setting a blind rivet and evaluating the acceptability of the set, said rivet being of the type having a frangible tubular body and an elongated mandrel that includes an enlarged head and a stem extending rearwardly of the head and through said frangible tubular body, said system comprising:

a hydraulically-operated blind rivet setting tool, said tool including a rivet pulling head for gripping and pulling said stem of said mandrel, said tool further including a hydraulic intensifier and a hydraulic line fluidly connecting said hydraulic intensifier with said pulling head, said hydraulic intensifier including a hydraulic fluid part and an air piston part, said hydraulic fluid part including a hydraulic fluid cavity and said air piston part including an air cylinder, said intensifier further including a piston assembly, said piston assembly including an air piston axially movable within said air cylinder and a shaft extending therefrom and operably movable within said hydraulic fluid cavity of said hydraulic fluid part;
a first transducer for measuring the hydraulic pressure of said setting tool applied to pull said rivet during a rivet set, said transducer being provided in operative association with said tool and adapted to produce a pressure output signal related said pressure applied to pull said rivet during a rivet set;
a second transducer for measuring the axial displacement of said piston assembly, said second transducer being provided in operative association with said tool and adapted to produce a displacement output signal related to the displacement of said piston assembly; and
a control circuit, said control circuit having circuitry to:

(a) receive said pressure output signal and said displacement output signal sequentially;
(b) produce from said pressure output signal and said displacement output signal a pressure-versus-displacement waveform;
(c) scan said pressure-versus-displacement waveform to identify the next location to the pressure peak as the displacement of said piston assembly at the break of the mandrel;
(d) compare the actual value of the displacement at break with a predetermined desired value.

9. The system for setting a blind rivet of claim 8 wherein said control circuit further including circuitry for scanning said pressure-versus-displacement waveform for slippage of said mandrel within said rivet pulling head represent-

ed by a drop in pressure, for noting the displacement point at said drop in pressure, for scanning said waveform for a subsequent rise in pressure, for noting the displacement point at said rise in pressure, for determining the difference between said drop in pressure and said rise in pressure, and for subtracting said difference from the overall displacement at the mandrel break.

10. The system for setting a blind rivet of claim 9 wherein said control circuit further includes circuitry for scanning said pressure-versus-displacement waveform for all occurrences of slippage and repeats the procedure of determining the difference between any subsequent drops and increases and subtracts any such differences from said overall displacement.

11. The system for setting a blind rivet of claim 8 wherein said control circuit further includes circuitry for identifying the value any offset of said piston assembly between sets of rivets and for subtracting said identified value from the displacement at the mandrel break.

12. The system for setting a blind rivet of claim 8 wherein said hydraulically-operated blind rivet setting tool further includes a compressor unit for operating said air piston, said tool further including a fluid line for fluidly connecting said compressor unit with said air cylinder.

13. The system for setting a blind rivet of claim 8 further including a pressure signal conditioning circuit provided between said transducer and said control circuit.

14. The system for setting a blind rivet of claim 9 further including an indicator operatively attached to said control circuit for signalling to an operator the correctness of the set based on said actual value of the displacement at break against a predetermined desired value.

15. The system for setting a blind rivet of claim 9 wherein said first transducer for measuring hydraulic pressure is an electrical pressure transducer and wherein said second transducer for measuring axial displacement of said piston assembly is a linear variable differential transformer.

16. The system for setting a blind rivet of claim 8 wherein said control circuit includes an integrator, a comparator connected with said integrator, and a programmable memory connected with said comparator.

17. A method for setting a blind rivet having a mandrel and for evaluating the acceptability of the set, said method including the steps of:

    setting a blind rivet in a desired position with a hydraulically-operated blind rivet setting tool having a hydraulic pressure intensifier, said intensifier including an axially movable piston assembly, said tool further including a mandrel gripping jaw assembly for gripping and pulling said mandrel;
    monitoring the hydraulic pressure required to set said blind rivet during the rivet setting process with a first transducer to produce pressure signals;
    monitoring the axial displacement of said piston assembly during said rivet setting process with a second transducer to produce displacement signals, said monitoring of said pressure signals and said displacement signals being done sequentially;
    producing a pressure-versus-displacement waveform based on said pressure signal and said displacement signal;
    producing a velocity waveform based on said displacement signals over time;
    scanning said pressure-versus-displacement waveform form to identify the pressure peak;
    identifying the displacement of the piston at the breakpoint of the mandrel by reading the location next to the pressure peak at break; and
    comparing the value of the displacement of the piston at break with a predetermined desired value.

18. The method for setting a blind rivet according to claim 17 including the additional steps of:

    scanning said pressure-versus-displacement waveform for slippage of said mandrel within said rivet pulling head represented by a drop in pressure;
    noting the displacement point at said drop in pressure;
    scanning said waveform for a subsequent rise in pressure;
    noting the displacement point at said rise in pressure;

determining the difference between said drop in pressure and said rise in pressure; and
subtracting said difference from the overall displacement at said mandrel break.

19. The method for setting a blind rivet according to claim 18 including the additional steps of:

scanning said pressure-versus-displacement waveform for all occurrences of slippage; and
repeating the procedure of determining the difference between any subsequent drops and increases and subtracts any such differences from said overall displacement.

20. The method for setting a blind rivet according to claim 17 including the additional steps of:

noting the occurrence of piston offset between sets of rivet sets;
assigning an offset value representing the amount of offset at said piston offset occurrence; and
subtracting said value from the displacement value at said mandrel break.

21. A system for setting a blind rivet and evaluating the acceptability of the set, said rivet being of the type having a frangible tubular body and an elongated mandrel that includes an enlarged head and a stem extending rearwardly of the head and through said frangible tubular body, said system comprising:

a hydraulically-operated blind rivet setting tool, said tool including a rivet pulling head for gripping and pulling said stem of said mandrel, said tool further including a hydraulic intensifier and a hydraulic line fluidly connecting said hydraulic intensifier with said pulling head, said hydraulic intensifier including a hydraulic fluid part and an air piston part, said hydraulic fluid part including a hydraulic fluid cavity and said air piston part including an air cylinder, said intensifier further including a piston assembly, said piston assembly including an air piston axially movable within said air cylinder and a shaft extending therefrom and operably movable within said hydraulic fluid cavity of said hydraulic fluid part;
a transducer for measuring the axial displacement of said piston assembly, said transducer being provided in operative association with said tool and adapted to produce a displacement output signal related to the displacement of said piston assembly; and
a control circuit, said control circuit having circuitry to:

(a) receive a series of said displacement output signals;
(b) time the intervals between said signals;
(c) produce from said signals a velocity waveform;
(c) scan said velocity waveform to determine the lowest initial value of velocity, this value representing the point at which the mandrel head enters the rivet body;
(d) scan said velocity waveform to determine the peak of said waveform subsequent to said lowest initial value of velocity;
(e) determine the difference between said lowest initial value and said subsequent peak;
(f) compare the actual determined difference with a predetermined desired value.

22. The system for setting a blind rivet of claim 21 wherein said hydraulically-operated blind rivet setting tool further includes a compressor unit for operating said air piston, said tool further including a fluid line for fluidly connecting said compressor unit with said air cylinder.

23. The system for setting a blind rivet of claim 21 further including a displacement signal conditioning circuit provided between said transducer and said control circuit.

24. The system for setting a blind rivet of claim 21 further including an indicator operatively attached to said control circuit for signalling to an operator the correctness of the set based on said actual determined difference against a predetermined desired difference.

25. The system for setting a blind rivet of claim 21 wherein said transducer for measuring axial displacement of said piston assembly is a linear variable differential transformer.

26. The system for setting a blind rivet of claim 21 wherein said control circuit includes an integrator, a comparator connected with said integrator, and a programmable memory connected with said comparator.

EP 0 738 551 A2

27. A method for setting a blind rivet having a mandrel and for evaluating the acceptability of the set, said method including the steps of:

setting a blind rivet in a desired position with a hydraulically-operated blind rivet setting tool having a hydraulic
pressure intensifier, said intensifier including an axially movable piston assembly, said tool further including a
mandrel gripping jaw assembly for gripping and pulling said mandrel;
monitoring the axial displacement of said piston assembly during said rivet setting process with a transducer
to produce a series of displacement signals;
timing the intervals between said sequential signals;
determining from said signals a velocity waveform;
scanning said velocity waveform to determine the lowest initial value of velocity, this value representing the
point at which the mandrel head enters the rivet body;
scanning said velocity waveform to determine the peak of said waveform subsequent to said lowest initial
value of velocity;
determining the difference between said lowest initial value and said subsequent peak; and
comparing the determined difference with a predetermined desired value.

28. A system for setting a blind rivet and evaluating the acceptability of the set, said rivet being of the type having a
frangible tubular body and an elongated mandrel that includes an enlarged head and a stem extending rearwardly
of the head and through said frangible tubular body, said system comprising:

a hydraulically-operated blind rivet setting tool, said tool including a rivet pulling head for gripping and pulling
said stem of said mandrel, said tool further including a hydraulic intensifier and a hydraulic line fluidly con-
necting said hydraulic intensifier with said pulling head, said hydraulic intensifier including a hydraulic fluid
part and an air piston part, said hydraulic fluid part including a hydraulic fluid cavity and said air piston part
including an air cylinder, said intensifier further including a piston assembly, said piston assembly including
an air piston axially movable within said air cylinder and a shaft extending therefrom and operably movable
within said hydraulic fluid cavity of said hydraulic fluid part;
a first transducer for measuring the hydraulic pressure of said setting tool applied to pull said rivet during a
rivet set, said transducer being provided in operative association with said tool and adapted to produce a
pressure output signal related said pressure applied to pull said rivet during a rivet set,
a second transducer for measuring the axial displacement of said piston assembly, said second transducer
being provided in operative association with said tool and adapted to produce a displacement output signal
related to the displacement of said piston assembly; and
a control circuit, said control circuit having circuitry to.

(a) receive said pressure output signal and said displacement output signal sequentially;
(b) produce from said pressure output signal and said displacement output signal a pressure-versus-
displacement waveform and a velocity waveform;
(c) scan said velocity waveform to determine the lowest initial value of velocity, this value representing
the point at which the mandrel head enters the rivet body;
(d) cross-reference the location of the determined lowest initial value of velocity on said pressure-versus-
displacement waveform to identify the entry load value;
(e) compare the entry load value with a predetermined desired value.

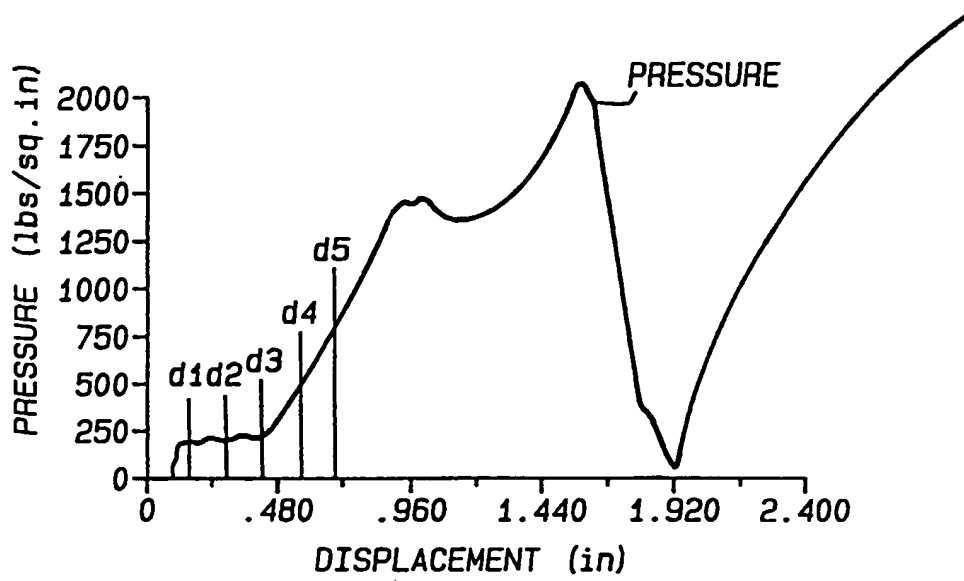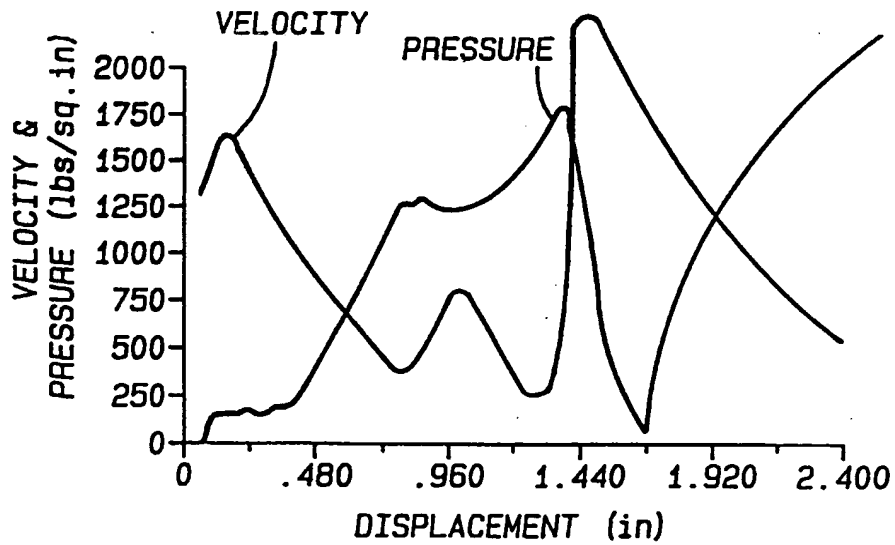29. The system for setting a blind rivet of claim 28 wherein said hydraulically-operated blind rivet setting tool further
includes a compressor unit for operating said air piston, said tool further including a fluid line for fluidly connecting
said compressor unit with said air cylinder.

30. The system for setting a blind rivet of claim 28 further including a pressure signal conditioning circuit provided
between said first transducer and said control circuit and a displacement signal conditioning circuit provided be-
tween said second transducer and said control circuit.

31. The system for setting a blind rivet of claim 28 further including an indicator operatively attached to said control
circuit for signalling to an operator the correctness of the set based on said actual entry load value against a
predetermined desired entry load value.

32. The system for setting a blind rivet of claim 28 wherein said first transducer for measuring hydraulic pressure is

13

an electrical pressure transducer and wherein said second transducer for measuring axial displacement of said piston assembly is a linear variable differential transformer.

33. The system for setting a blind rivet of claim 29 wherein said control circuit includes an integrator, a comparator connected with said integrator, and a programmable memory connected with said comparator.

34. A method for setting a blind rivet having a mandrel and for evaluating the acceptability of the set, said method including the steps of:

> setting a blind rivet in a desired position with a hydraulically-operated blind rivet setting tool having a hydraulic pressure intensifier, said intensifier including an axially movable piston assembly, said tool further including a mandrel gripping jaw assembly for gripping and pulling said mandrel;
> monitoring the hydraulic pressure required to set said blind rivet during the rivet setting process with a first transducer to produce pressure signals;
> monitoring the axial displacement of said piston assembly during said rivet setting process with a second transducer to produce displacement signals, said monitoring of said pressure signals and said displacement signals being done sequentially;
> producing a pressure-versus-displacement waveform based on said pressure signals and said displacement signals;
> producing a velocity waveform based on said displacement signals over time;
> scanning said velocity waveform to determine the lowest initial value of velocity, this value representing the point at which the mandrel head enters the rivet body;
> cross-referencing the location of the determined lowest initial value of velocity on said pressure-versus-displacement waveform to identify the entry load value; and
> comparing the entry load value with a predetermined desired entry load value.
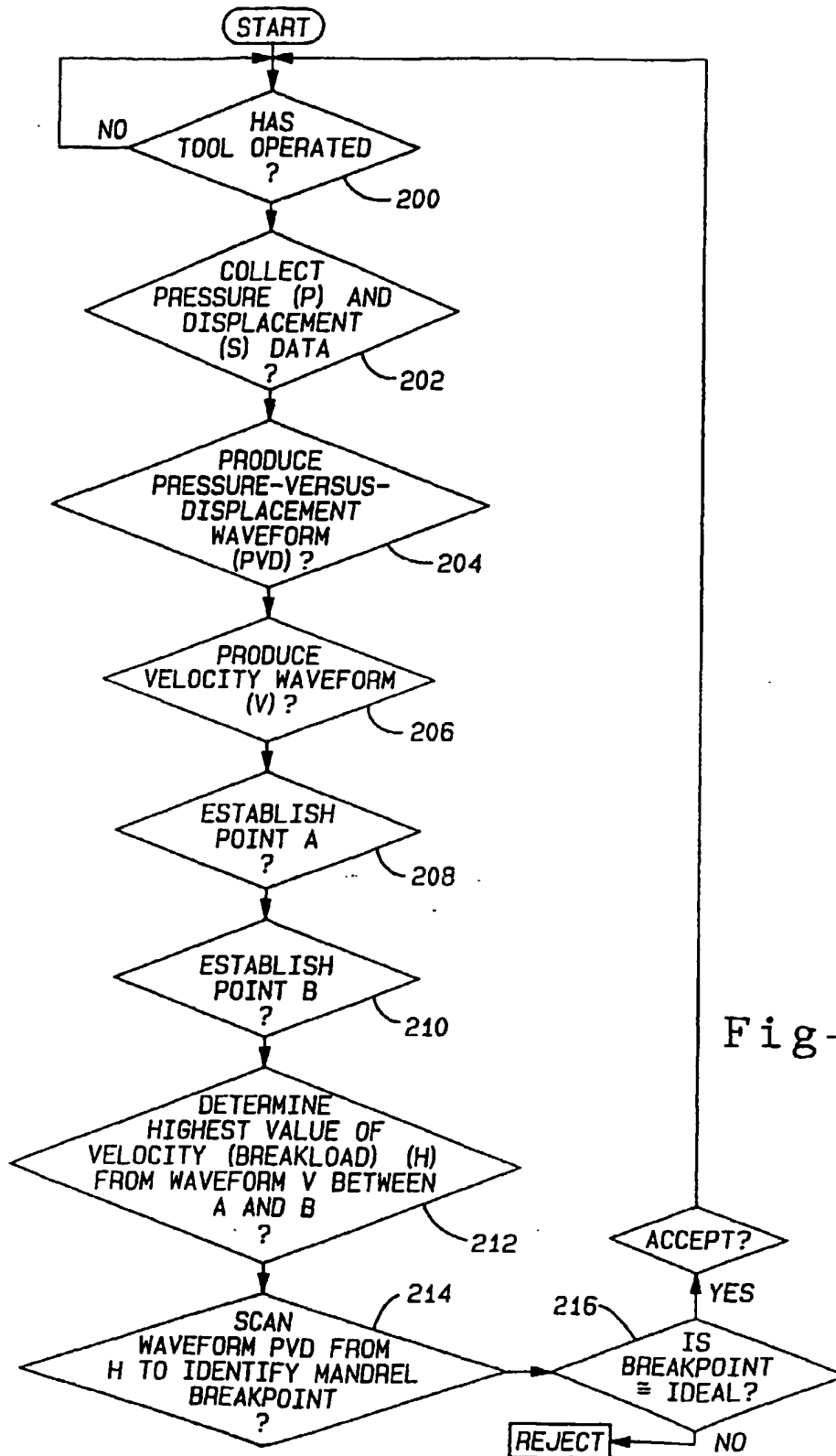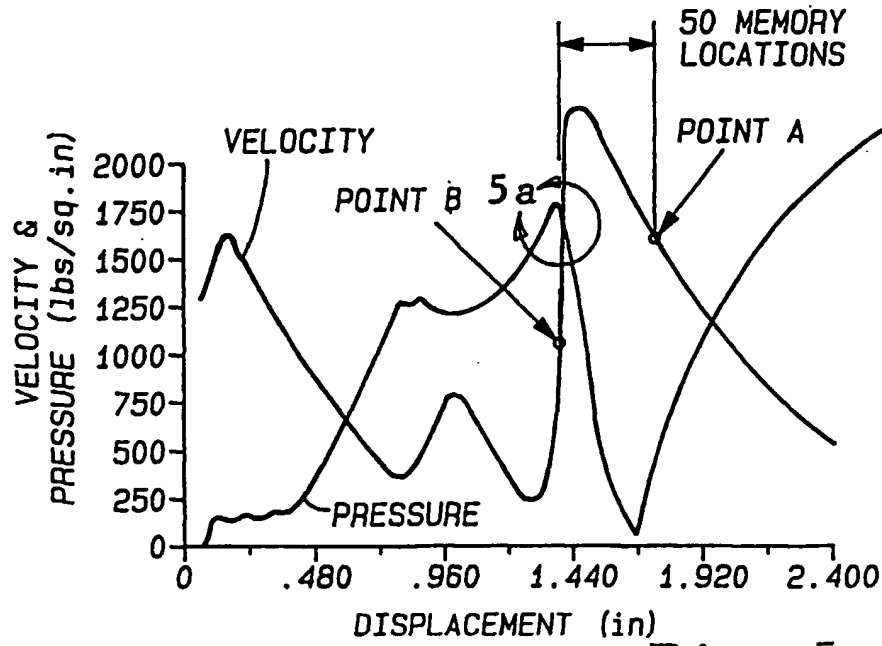
Fig-1

Fig-2

Fig-3

START

HAS
TOOL OPERATED
?
— 200
NO

COLLECT
PRESSURE (P) AND
DISPLACEMENT
(S) DATA
?
— 202

PRODUCE
PRESSURE-VERSUS-
DISPLACEMENT
WAVEFORM
(PVD) ?
— 204

PRODUCE
VELOCITY WAVEFORM
(V) ?
— 206

ESTABLISH
POINT A
?
— 208

ESTABLISH
POINT B
?
— 210

DETERMINE
HIGHEST VALUE OF
VELOCITY (BREAKLOAD) (H)
FROM WAVEFORM V BETWEEN
A AND B
?
— 212

— 214
SCAN
WAVEFORM PVD FROM
H TO IDENTIFY MANDREL
BREAKPOINT
?

216 —
IS
BREAKPOINT
≅ IDEAL?

ACCEPT?
YES

REJECT   NO

Fig-4

17
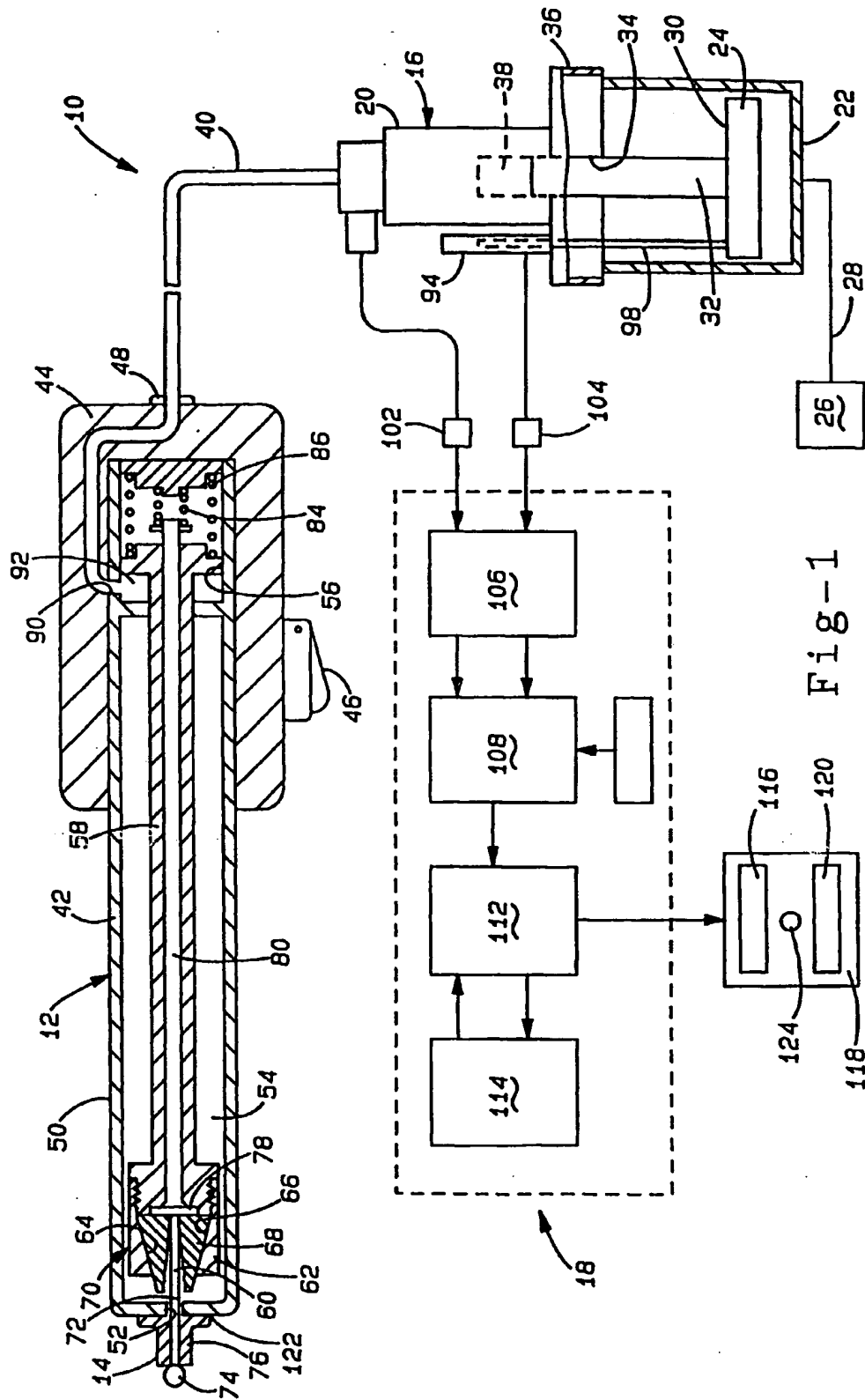
Fig-5

Fig-5a

Fig-6a   Fig-6b   Fig-6c

Fig-7

Fig-7a

Fig-8
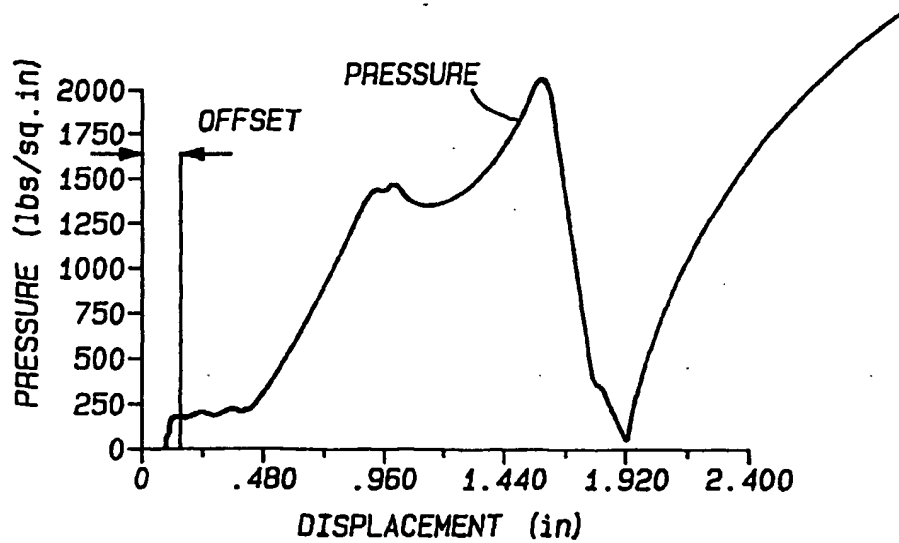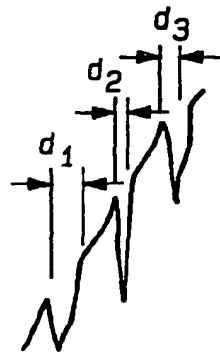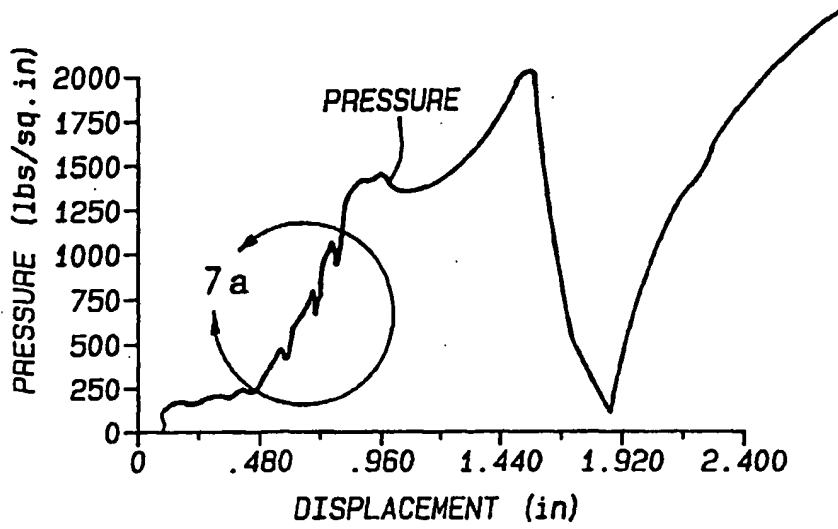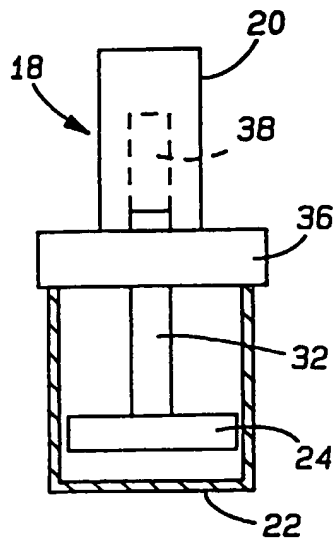
Fig-9a

Fig-9b

Fig-10a

Fig-10b

START

HAS TOOL OPERATED ? — 200   NO

COLLECT PRESSURE (P) AND DISPLACEMENT (S) DATA ? — 202

PRODUCE PRESSURE-VERSUS-DISPLACEMENT WAVEFORM (PVD) ? — 204

PRODUCE VELOCITY WAVEFORM (V) ? — 206

ESTABLISH POINT A ? — 208

ESTABLISH POINT B ? — 210

DETERMINE HIGHEST VALUE OF VELOCITY (BREAKLOAD) (H) FROM WAVEFORM V BETWEEN A AND B ? — 212

SCAN WAVEFORM PVD FROM H TO IDENTIFY MANDREL BREAKPOINT ? — 214

IDENTIFY DISPLACEMENT OF PISTON AT BREAK? — 218

COMPENSATE FOR JAW SLIPPAGE ? — 220

COMPENSATE FOR PISTON OFFSET ? — 222

ACCEPT?

YES

IS BREAKPOINT ≅ IDEAL? — 224   NO → REJECT

Fig-11

21

Fig-12

Fig-13

Fig-13a

Fig-14

Fig-14a

START

HAS TOOL OPERATED ? — 200
NO

COLLECT PRESSURE (P) AND DISPLACEMENT (S) DATA ? — 202

PRODUCE PRESSURE-VERSUS-DISPLACEMENT WAVEFORM (PVD) ? — 204

PRODUCE VELOCITY WAVEFORM (V) ? — 206

SCAN WAVEFORM V TO IDENTIFY LOWEST INITIAL VELOCITY ? — 226

CROSS-REFERENCE LOCATION A TO WAVEFORM PVD TO IDENTIFY POINT (E) ? — 232

IS ≅ IDEAL? — 234
NO → REJECT
YES

ACCEPT?

Fig-15